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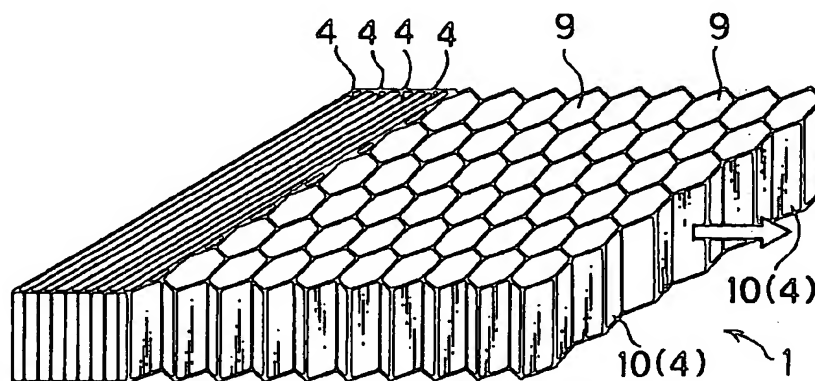
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### (54) Honeycomb core

(57) A honeycomb core or honeycomb structure 1 comprises a two-dimensional arrangement of hollow cylindrical cells individually separated by cell walls made of constructive sheets 4. Each constructive sheet comprises a mixture complex of para-aramid fibers 2 and meta-aramid pulp material. The para-aramid fibers 2 occupy a weight percentage not less than 20% and less than 50% of the entirety. The honeycomb core is made by either the expanding method comprising the

steps of stacking a plurality of such constructive sheets 4, applying stripes of adhesive and then extending the stack or by the corrugating method comprising the steps of corrugating respective constructive sheets, stacking and bonding the corrugated sheets. If desired, after-treatment for reinforcement may be executed to apply or impregnating phenolic resin or other impregnating agent.

FIG. 2C



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## Description

The present invention relates to a honeycomb core or honeycomb structure using aramid fibers as a material of its constructive sheets.

Constructive sheets used in widely-used conventional honeycomb structures to form cell walls for separating individual cells were made by processing a nonwoven material of aramid fibers into sheets. That is, a mixture mainly including short-cut meta-aramid fibers are made into sheets, and these sheets are used as constructive sheets of such conventional honeycomb structures. One of typical methods of making such constructive sheets into a honeycomb structure comprises applying stripes adhesive onto surfaces of the constructive sheets, stacking and bonding them together, and pulling them to expand their distances between their non-bonded faces. Another method comprises deforming the constructive sheets into corrugated forms, stacking and bonding them together with bottoms of the corrugation of one sheet joining with tops of the corrugation of another sheet. By either method, constructive sheets are made to behave as cell walls for separating individual cells, and a two-dimensional arrangement of such individual cells makes a honeycomb structure.

These conventional honeycomb structures, however, involve some problems discussed below.

Meta-aramid fibers used to make up the constructive sheets have a relatively low Young's modulus of elasticity. Due to this, conventional honeycomb structures were often weak and were unacceptable for use as a constructive material that must be sufficiently strong.

In such cases, relatively weak honeycomb structures were conventionally reinforced by impregnation or coating using a significant amount of an impregnating agent, such as phenolic resin or the like, having a high Young's modulus of elasticity, and desired high strengths were realized by increasing the amount of impregnating or coating agents. Due to this, such conventional honeycomb structures were too heavy, and their strength-to-weight ratios were too low beyond acceptable values required for honeycomb structures in general.

It is therefore an object of the present invention to provide a honeycomb core with a high strength.

A further object of the invention is to provide a lightweight honeycomb core having an excellent strength-to-weight ratio.

A still further object of the invention is to provide a honeycomb core easy to manufacture at a low cost.

According to the invention, there is provided a honeycomb core comprising a two-dimensional arrangement of hollow cylindrical cells individually separated by cell walls formed by constructive sheets which are made of a mixture of para-aramid fibers and meta-aramid pulp material. The para-aramid fibers occupy a weight percentage not less than 20% and less than 50% of the entirety.

Preferably, the para-aramid fibers are cut into short fibers, and mixed with meta-aramid pulp material which is also cut into fine chips.

If the para-aramid is less than 20%, strength of the constructive sheet will not reach a required value. If it is 50% or more, elasticity of the constructive sheet will decrease below a required value.

Since the para-aramid fibers exhibit a high elastic modulus, it inherently increases the strength of the honeycomb core and does not require additional reinforcement by coating or impregnation by a large amount of impregnating agent. This means that finished honeycomb cores are light in weight and have excellent strength-to-weight ratios. The meta-aramid pulp material behaves as a binder and makes the paper-making process easier. The use of an appropriate amount of the meta-aramid pulp material also contributes to minimizing the amount of expensive para-aramid fibers which would otherwise increase the production cost of the honeycomb core unacceptably.

The foregoing and other objects, features and advantages of the invention become more apparent in the light of the following description of preferred embodiments thereof, as illustrated in the accompanying drawings.

In the accompanying drawings:

Figs. 1A to 1C are perspective views of a honeycomb core embodying the invention, with Fig. 1A showing a sheet just after a paper-making process, Fig. 1B showing a process of making a constructive sheet, and Fig. 1C showing a process of applying stripes of adhesive onto the constructive sheet;

Figs. 2A to 2C are perspective views of a stack of the constructive sheets, with Fig. 2A showing a process of stacking and bonding a plurality of the sheets of Figs. 1A to 1C by applying heat and pressure, Fig. 2B showing a process of cutting the stack of the constructive sheets into segments, and Fig. 2C showing a process of expanding distances between the respective constructive sheets in a segmental stack of the constructive sheets into a honeycomb structure;

Figs. 3A and 3B are views showing optional processing of the honeycomb core, with Fig. 3A showing a step of immersing the honeycomb structure into an impregnating solution, and Fig. 3B showing a process of drying and setting the impregnated honeycomb structure;

Fig. 4 is a graph showing an experimental result of compressive strengths of some comparative structures and of honeycomb structures according to embodiments of the invention; and

Fig. 5 is a graph showing a load curve, in terms of compressive displacement with load, obtained by a compressive breakdown test of an inventive honeycomb structure and another honeycomb structure by using a universal testing machine.

The invention is described below in detail, taking an embodiment illustrated in different steps of a manufacturing process in the drawings.

Para-aramid fibers 2 are used as aramid fibers, a sort of nylon fibers. The para-aramid fibers 2 used as a major component are mixed with meta-aramid pulp material (not shown) and one or more other components, and are made into a sheet material as shown in Fig. 1A by a paper-making process. Apparently, the para-aramid fibers 2 used here are prepared into short fibers in a preceding chopping process using a cutter. Also the meta-aramid pulp material is used after being cut into fine chips, and further processed in a solution of sulfuric acid or other chemical bath into curled threads easy for intertwinement and interconnection. The mixture ratio of para-aramid fibers 2 is chosen appropriately from values not less than 20 and less than 50 weight percent.

The sheet material shown in Fig. 1A is subsequently fed in between heat rolls 3 for applying heat and pressure to the sheet material. Thus the sheet material is extruded from the heat rolls 3 in the form of the constructive sheet 4 having complete flatness and integrality. If the para-aramid fibers 2 and the meta-aramid pump material are still insufficiently bound together in the constructive sheet 4 or if the surface of the constructive sheet 4 exhibits any unevenness, a polymeric binder substance, such as phenolic resin, in the range of 5 to 30 weight percent of the entirety may be added prior to making the sheet material of Fig. 1A. Since the phenolic resin is inexpensive, its use gives another advantage that the entire material cost of the honeycomb core decreases.

After that, as shown in Fig. 1C, stripes of adhesive 6 are applied onto a surface of the constructive sheet 4 by using an adhesive applying roll 5. Numeral 7 denotes a back-up roll. After the stripes of adhesive 6 are dried, a plurality of such constructive sheets 4 are stacked, one over another, such that the pitch of the stripes 6 on one constructive sheet is offset by half the pitch from the stripes 6 on another constructive sheet. The stack of the constructive sheets 4 is then heated and pressed, so that the stripes of adhesive 6 are once melted and then set to firmly bind the sheets 4 together. Subsequently, the stack of the constructive sheets 4 is cut into segments of a desired size along a line parallel to the stripes of adhesive 6.

Each segmental stack of the constructive sheets 4 is then extended in its stacking direction so as to expand distances between non-bonded opposite faces of respective constructive sheets 4. Thus the honeycomb core 1 having a two-dimensional arrangement of a number of cells is obtained.

Instead of the aforementioned extending method, individual constructive sheets 4 may be corrugated by using a gear or a rack, and a plurality of such corrugated sheets 4 may be stacked and bonded together, with troughs of one sheet 4 joining with peaks of another

sheet 4, to form a similar configuration of the honeycomb core 1.

The honeycomb core 1, made by the foregoing steps, defines a two-dimensional arrangement of a number of hollow cylindrical cells 9 which are individually separated by cell walls 10 made by the constructive sheets 4, as shown in Fig. 2C.

Although the honeycomb core 1 already has a sufficient strength and an excellent strength-to-weight ratio because of the para-aramid fibers 2 used to make its constructive sheets 4, additional treatment may be applied to the honeycomb core 1 if a higher strength is desired.

Figs. 3A and 3B show such additional treatment for reinforcement. As shown in Fig. 3A, the honeycomb core 1 is immersed in a bath 12 containing a solution of an impregnating agent 12 which may comprise a polymeric binder substance, such as phenolic resin, having a high Young's modulus of elasticity. Then the honeycomb core 1, impregnated or coated by the impregnating agent 11, is extracted from the bath 12, and sent to a processing chamber 13 for drying and heating treatments using a heat source 14. Thus the impregnating agent 11 is thermally set, coating the cell walls 10. The coating or impregnating process may be repeated until weight and strength of a particular honeycomb core 1 reach specific values desired for the honeycomb core 1.

By using an appropriate amount of para-aramid fibers 2, namely, 20% or more and less than 50% in weight of the entirety, in conjunction with an appropriate amount of meta-aramid fibers to make the constructive sheets, intended advantages of the invention are totally attained as summarized below.

First, because of the para-aramid fibers having a higher Young's modulus of elasticity than that of meta-aramid fibers, the cell walls 10 and the honeycomb core 1 have a higher strength than conventional honeycomb structures have. If the weight percentage of the para-aramid fibers 2 is less than 20%, the strength of the honeycomb core 1, such as compressive strength, would be insufficient. If it is 50% or more, the structure would become stiff and lose toughness.

Second, since the honeycomb core 1 with an appropriate amount of para-aramid fibers is inherently strong as stated above, it basically needs no after-treatment for reinforcement by impregnation. Even if any impregnating agent 11 is still used, its amount can be significantly reduced as compared with conventional structures. Therefore, the honeycomb core 1 according to the invention is very light, and has an excellent strength-to-weight ratio.

Third, the use of para-aramid fibers of a weight percentage less than 50% in conjunction with an appropriate amount of meta-aramid pulp material not only makes the paper-making process easy but also provides a reasonable manufacturing cost which would otherwise become unacceptably high if an excessive amount of expensive para-aramid fibers is used.

Figs. 4 and 5 show experimental results regarding the strength of the honeycomb core according to the invention, referred to above as the first advantage. Used in these tests is a square honeycomb core with each side 76 mm (about 3 inches) long, 20 mm thick, and weighing 48 kg/m<sup>3</sup> (about 3 pounds/cubic feet), in which each cell is 3 mm (about 1/8 inch) large.

Used in the compressive strength test of Fig. 4 are (1) a honeycomb structure comprising a mixture of meta-aramid fibers and phenolic resin (labelled META in the drawing); (2) a honeycomb core according to an embodiment of the invention, comprising a mixture of 45 weight percent of para-aramid fibers 2, 35 weight percent of meta-aramid pulp material and 20 weight percent of phenolic resin (labelled PARA-45% in the drawing); (3) a honeycomb core according to another embodiment of the invention, comprising a mixture of 35 weight percent of para-aramid fibers 2, 45 weight percent of meta-aramid pulp material, and 20 weight percent of phenolic resin (labelled PARA-35% in the drawing); and (4) a honeycomb core departing from the invention, comprising a mixture of 18 weight percent of para-aramid fibers 2, 62 weight percent of meta-aramid fibers, and 20 weight percent of phenolic resin (labelled PARA-18% in the drawing).

The graph of Fig. 4 shows that the PARA-45% structure of (2) and the PARA-35% structure of (3) represent compressive strengths above that of the META structure of (1) but the PARA-18% structure of (4) represents a compressive strength below that of the META structure of (1). It is therefore apparent from the result of the test that 20 weight percent is the lower limit of para-aramid fibers 2 to attain the objects of the invention.

Used in the compressive breakdown test of Fig. 5 are the PARA-35% structure according to one of the embodiments of the invention shown at (3) in Fig. 4, comprising a mixture of 35 weight percent of para-aramid fibers 2, 45 weight percent of meta-aramid pulp material and 20 weight percent of phenolic resin; and a honeycomb structure departing from the invention, comprising 60 weight percent of para-aramid fibers 2, 20 weight percent of meta-aramid pulp material and 20 weight percent of phenolic resin (labelled PARA-60% in the drawing).

The graph of Fig. 5 shows that the PARA-35% structure begins to break down with a maximum load of about 1,400 kg but the breakage progresses only gradually and slowly, which shows a high toughness of the PARA-35% structure. In contrast, the PARA-60% departing from the invention rushes to break down after a breakage starts with a maximum load of about 1,800 kg, which shows unacceptable stiffness and liability to destruction of the PARA-60% structure. This tendency noticeably appears when para-aramid fibers 2 exceeds 50 weight percent. It is therefore apparent that 50 weight percent should be the upper limit of para-aramid fibers 2 in the honeycomb core 1 to attain the objects of the invention.

Although the invention has been shown and described with respect to preferred embodiments thereof, it should be understood by those skilled in the art that the foregoing and other changes and omissions in the form and detail thereof may be made therein without departing from the spirit and scope of the invention.

## Claims

1. A honeycomb core comprising a two-dimensional arrangement of hollow cylindrical cells individually separated by cell walls formed by constructive sheets, wherein each said constructive sheet is a mixture of para-aramid fibers and meta-aramid pulp material, said para-aramid fibers occupying a weight percentage not less than 20% and less than 50% of the entirety.
2. The honeycomb core according to claim 1 wherein each said constructive sheet comprises a mixture complex consisting of para-aramid fibers and meta-aramid pulp material.
3. The honeycomb core according to claim 1 wherein each said constructive sheet comprises a mixture complex including para-aramid fibers, meta-aramid pulp material and at least one other component.
4. The honeycomb core according to claim 1 wherein each said constructive sheet is made by cutting the para-aramid fibers into short fibers, using them as a major component thereof, cutting the meta-aramid pulp material into fine strips, then treating the fine strips with a chemical liquid into forms easy to intertwine, using them as a binder, mixing the short fibers of para-aramid fibers and the chemical-treated fine strips of meta-aramid pulp material, making the mixture into the form of a sheet, and then applying heat and pressure to the sheet-formed mixture to increase the integrality of respective materials in the mixture.
5. The honeycomb core according to claim 1 wherein said cell walls are reinforced by phenolic resin or other polymeric binder material applied to surfaces of or impregnated into said cell walls.
6. The honeycomb core according to claim 3 wherein said at least one other component is phenol or other polymeric binder material in the amount of 5 to 30 weight percent of the entirety.

FIG.1A

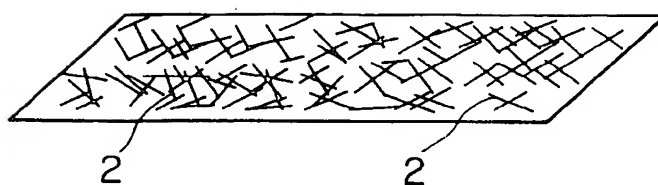


FIG.1B

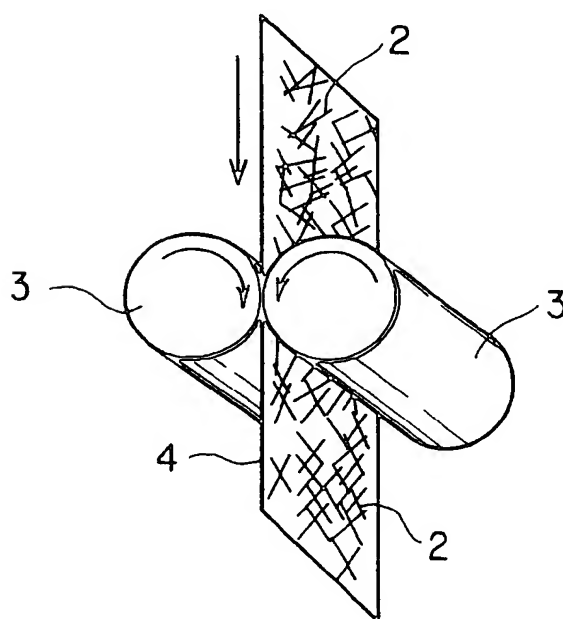


FIG.1C

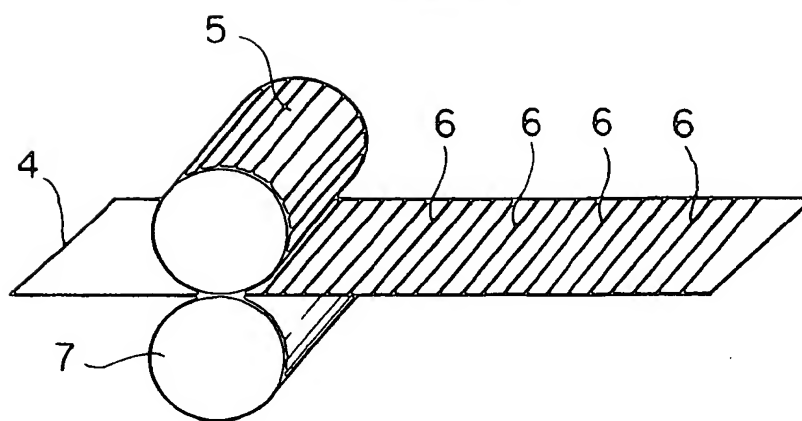


FIG.2A

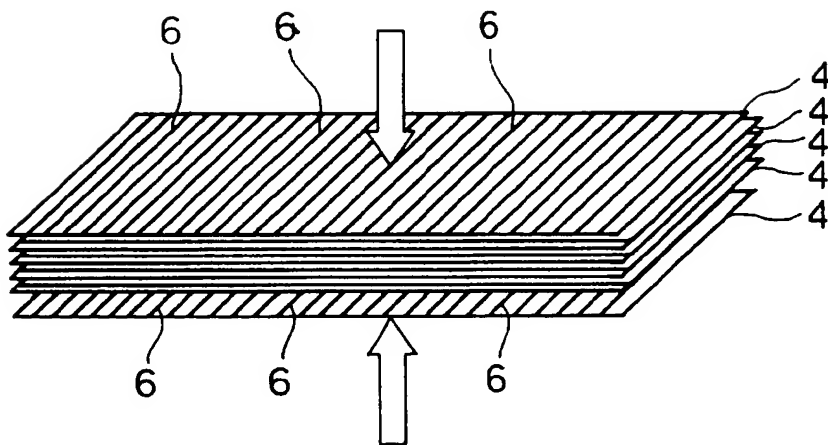


FIG.2B

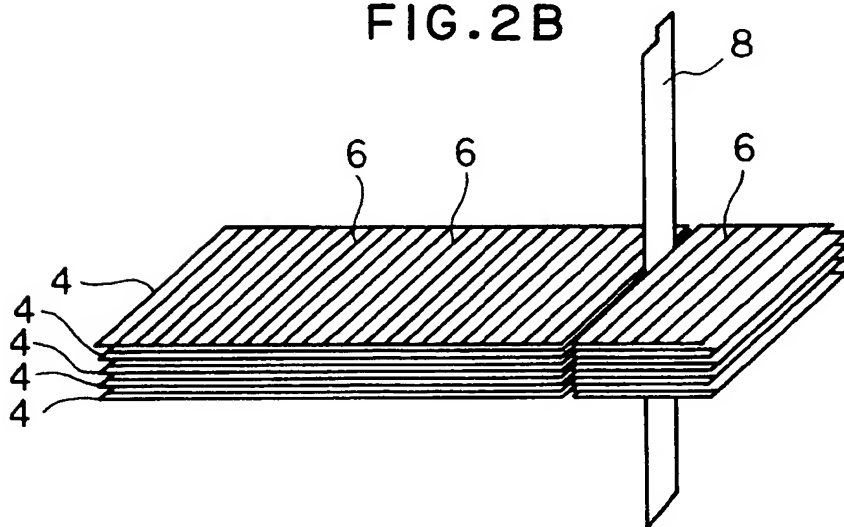


FIG.2C

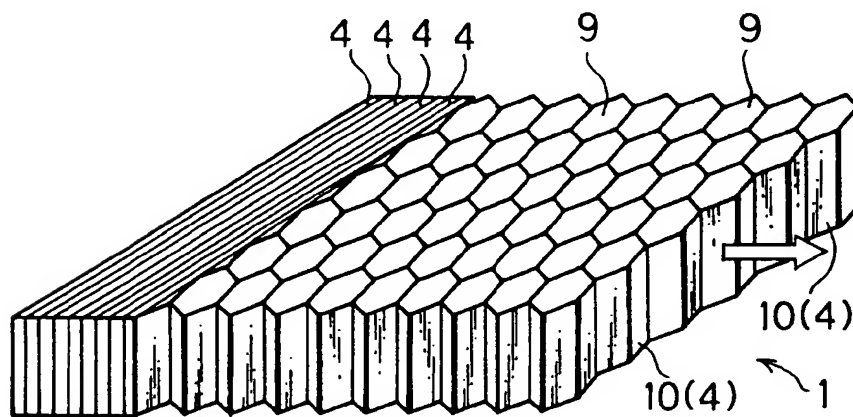


FIG. 3A

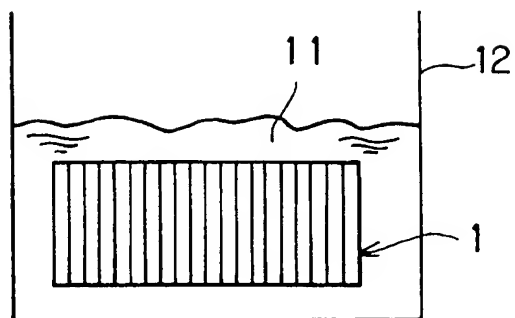


FIG. 3B

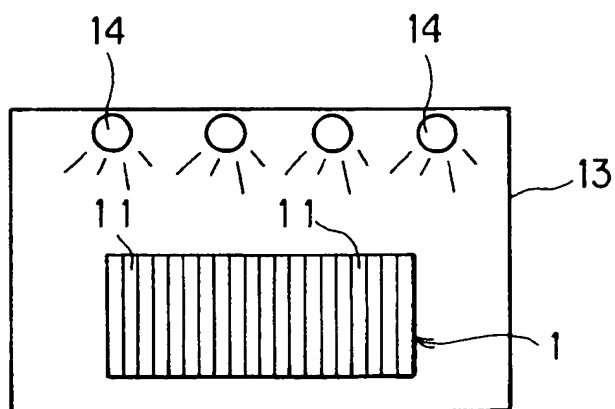


FIG. 4

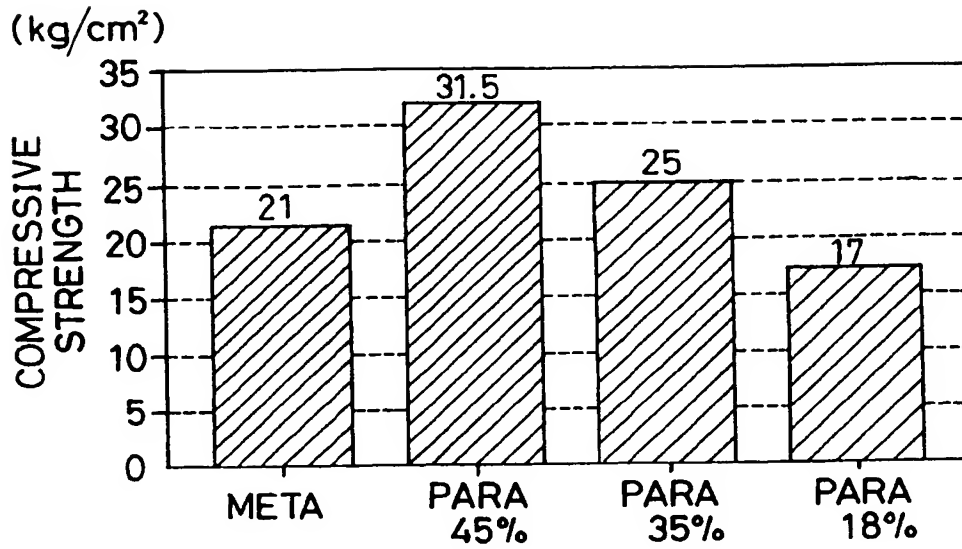
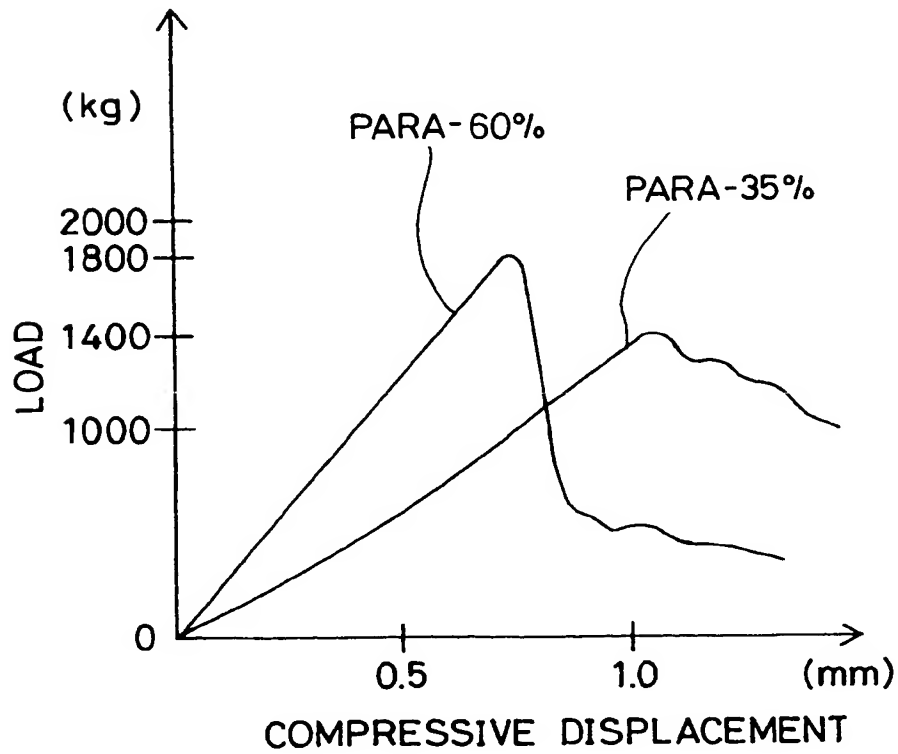


FIG. 5







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## EUROPEAN SEARCH REPORT

Application Number  
EP 95 30 2903

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	RESEARCH DISCLOSURE, vol. 188, no. 18823, December 1979 HAVANT GB, page 674 DISCLOSED ANONYMOUSLY 'Mixed aramid papers'	1-3,5	B29D31/00 D21H13/26 //B29K61:04, B29K277:00, B29L31:60
Y	* page 674, left column, line 7 - line 41 *	4,6	
Y	--- EP-A-0 467 286 (E.I. DU PONT DE NEMOURS AND COMPANY) * claims 1,3 *	4,6	
Y	--- US-A-3 756 908 (GEORGE CONRAD GROSS) * column 3, line 1 - column 4, line 58 * * column 6, line 42 - line 45; claims 1,2 *	4	
A	--- DATABASE WPI Week 9334 Derwent Publications Ltd., London, GB; AN 93-269881 & JP-A-05 186 608 (TEIJIN LTD) , 27 July 1993 * abstract *	1-6	
A	--- US-A-5 223 094 (BIROL KIRAYOGLU ET AL) * claim 1 *	1	
A	--- EP-A-0 392 559 (E.I. DU PONT DE NEMOURS AND COMPANY) * claims 1,11 *	1	
A	--- EP-A-0 330 163 (TEIJIN LIMITED) * claim 1 *	1	
A	--- US-A-5 320 892 (GARY L. HENDREN ET AL) * column 1, line 35 - column 2, line 37 * -----	1	
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 17 October 1995	Examiner Van Nieuwenhuize, D
<p><b>CATEGORY OF CITED DOCUMENTS</b></p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons</p> <p>Δ : member of the same patent family, corresponding document</p>			

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